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ELECTROPHYSIOLOGICAL AND QUANTITATIVE ELECTROENCEPHALOGRAPHIC MEASUREMENTS AFTER TREATMENT BY TRANSCEREBRAL MAGNETIC FIELDS GENERATED BY COMPACT DISC THROUGH A COMPUTER SOUND CARD: THE SHAKTI TREATMENT

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Quantitative electroencephalographic activity over the left and right frontal, temporal, parietal, and occipital lobes was obtained on 4 successive weeks in 12 subjects before they were exposed cerebrally for 30 min to one of two configurations of weak complex magnetic fields or to a sham-field condition. The two configurations were Shakti (c Todd Murphy) and the set of 4 solenoids (Koren boxes) generating a burst-firing magnetic field through the temporal lobes. Compared to baseline measurements there were no statistically significant differences in treatments for relative changes in power over these regions within the delta, theta, low alpha, beta, or gamma ranges. However within the high alpha range (10.5 Hz to 13 Hz), there was a significant interaction between session

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and type of treatment that was due primarily to the Shakti treatment. These changes were congruent with the subjective experiences reported by some users of the technology.

Keywords alpha activity, burst-firing, complex magnetic fields, quantitative electroencephalographic activity, Shakti

Several researchers (Anninos et al., 1991; Persinger et al., 1997; Richards et al., 2002; Subrahmanyam et al., 1985) have reported that brief exposures to weak complex magnetic fields can produce shifts in the power spectra for specific frequencies or bands of frequencies of human electroencephalographic activity. Because large numbers of neurons contribute to this macroscopic activity, such changes might be considered definitive evidence that weak magnetic fields can affect brain function. Although this crude measure does not easily reveal the complexity of the recondite information generated intracerebrally, the presence or absence of specific changes could contribute to the identification of the conditions that may ultimately allow the isolation of this information.

The first neuroscientists to clearly demonstrate that weak complex magnetic fields designed to simulate natural patterns of neuroelectrical activity could affect quantitative electroencephalographic activity and modify abnormal conditions were Anninos et al. (1991). The Shakti method was developed by Todd Murphy who was the first neuroscientist to construct a system of complex magnetic fields that could he accessed through the Internet and applied through a computer's sound card to generate complex magnetic fields over or through specific regions of the brain. These specific patterns were derived from the physiologically patterned sequences associated with long-term potentiation in hippocampal slices (Rose et al., 1988) and paroxysmal discharges in the amygdala associated with opiate-like effects. When applied through the brain or the whole body as weak magnet fields, these configurations have produced enhancement of memory in rats and human beings (McKay & Persinger, 2000; Richards et al., 1996) and elevated nociceptive thresholds (reduced pain) in rats (Martin et al., 2003).

The present experiment was designed to discern if three, weekly sessions of exposures to the fields available from the Shakti proce-

dure would produce significant changes in quantitative electroencephalographic activity. To determine if any effects were specific to the application geometry and patterns associated with the Shakti method or nonspecifically associated with simply the presence of magnetic fields, other subjects were exposed to burst-firing magnetic fields applied through another method as described in Baker-Price and Persinger (1996). Both groups were compared with sham-field controls. It was reasoned that if either treatment produced a conspicuous effect, only four subjects per group would be required to produce an effect size to be statistically significant at the $p < .05$ level.

METHODS

Subjects

A total of 12 men and women, 19 to 25 years of age, volunteered as subjects. They had been enrolled in first and second year university courses during a summer session. They received bonus marks for participation.

Procedure

Electroencephalographic measurements. For 30 min once per week for 4 successive weeks the subjects' electroencephalographic activity was recorded by a Grass Instruments Model 8-16C machine, Silver electrodes were attached to the scalp by EC2 cream over the left frontal (F7), temporal (T3), parietal (P3), and occipital (O1) lobes and over the right frontal (F8), temporal (T4), parietal (P4), and occipital (O2) lobes. During the measurements the subjects sat in a comfortable arm chair while they were blindfolded.

The filter selections for each channel were set for the standard range between 0.5 Hz and 35 Hz. Four 20-s samples of monopolar quantitative electroencephalographic activity, referenced to the ear, were completed simultaneously from all 8 leads. The record was obtained while the strip chart was operating simultaneously in order to ensure no artifacts contaminated the quantitative measurements. The four 20-s recordings were later averaged into one record in

order to improve the reliability and intrinsic validity of the measurement.

The machine was interfaced via a custom shielded cable, a parallel analogue shielded interface cable (Nat. Inst. SH100100), and a shielded connector block (Nat. Inst. SCB-100) to a National Instruments PCI-6071E Multi I/O Board computer interface card. The data collection was extracted by a DELL Dimension 8100 Personal Computer on a Windows 2000 Professional Platform. A custom-designed user interface or Virtual Instrument (VI) using National Instruments Labview (Version 6.0i-2000) allowed the multichannel sample to be manually recorded to fixed disk.

The digital electroencephalographic recordings were analyzed with a custom-programmed software package for Fast Fourier Transforms. The software was compiled under Borland Pascal (version 5.5, 1986). The Fast Fourier Transform utilized three publicly available Pascal software libraries for standard mathematical functions that included FMATH v2.5: Debord, 2001; FOURIER: Cross & Debord, 1998; and MATRICES v2.1: Debord, 2001.

The frequency spectral outputs from each lead from the four lobes of the two hemispheres for the six patterns were extracted into a single file for five increments of frequencies that included delta (1 to 4 Hz), theta (4.0 to 7.9 Hz), lower alpha (8.0 to 10.4 Hz), upper alpha (10.5 to 13.0 Hz), lower beta (13.1 Hz to 20 Hz), and gamma (35 Hz to 45 Hz) activity. This file was then uploaded to a VAX System for analyses.

Before the experiment began the authors had ensured that the values from the quantitative analyses of the electroencephalographic data were valid by counting by hand the numbers of seconds during the 20 s of extraction that contained alpha rhythms and correlating these values with the numerical values for power within the alpha range for a single subject. The subject had been asked to open her eyes 4 times and close her eyes 3 times for 20 s each just before the quantitative recordings began. The Pearson r correlation between the percentage of 1-s increments of alpha rhythms per 20-s sampling (range 10% to 100%) and the actual power values (range 3 to 13 microV) was 0.93. The Spearman rho value was 0.97 ($df = 7$).

In order to accommodate individual differences the means of the raw data for the measurements for each of the frequency increments

for the electroencephalographic power for each person was extracted for the baseline measurement (before the first field exposure) . All subsequent measures during the next three weeks for each of the eight leads was divided by these values obtained during the baseline. These ratios were employed as the data,

Magnetic field and sham exposures. The same subject always received the same treatment each week within a few minutes *after* the collection of the electroencephalographic data. All subjects sat within a comfortable arm chair in an acoustic chamber and were blindfolded during the exposure. The sham-field group wore either the Koren boxes over the temporal lobes (just above the ears) or the Shakti helmet. However the computers were not activated during their sessions.

The subjects receiving the burst-firing pattern generated by the Koren boxes (each containing four sets of solenoids) were presented for about .7 s once every 3 s across the temporoparietal lobes (Baker-Price & Persinger, 1997, 2003) for 30 min. The duration of each point composing the pattern was 3 ms. A diagram of the equipment has been published elsewhere (Persinger et al., 2000). Essentially a column of numbers between 0 and 255 were transformed to incremental voltages between –5 V and +5 V (127 = 0 V) and then transformed through a customconstructed digital-to-analogue converter to current that when passed through the solenoids (small reed switches) generated the magnetic fields.

For the subjects who received the Shakti treatment a modified bicycle helmet was placed on their heads. Embedded within the helmet were three sets of solenoids at the level of the prefrontal, parietal, and temporal lobes. The circuit was designed so that the solenoids over the right hemisphere generated a theta-burst pattern of one pulse followed 170 ms later by four high frequency pulses about 3.8 times per sec. This pattern, when delivered as electrical current to hippocampal slices, produced robust long-term potentiation (Rose et al., 1988). This pattern was delivered once every 4.76 s. The intensity near the surface of the scalp was about 1 microTesla (10 mG). Simultaneously, over the left hemisphere the burst-firing pattern was generated to the solenoids.

The magnetic field signals were generated through a CD disc from a personal computer. The intensity, approximately near the

level of the scalp, was 1 microTesla (10 mG) for the left side, which delivered the burst-firing pattern. The right side of the Shakti helmet delivered the "LTP" (long-term potentiation) pattern. Its intensity was approximately 0.5 microTesla (5 mG).

The primary differences between the two application geometries were the following. First, the fields from the Koren boxes were generated between each of the four pairs of solenoids every 0.5 s (2 s per cycle) through the brain while the Shakti device applied the fields topically. Second, the left and right sides of the brain received different pulses from the Shakti helmet but the same pattern from the Koren boxes. Third, the magnetic fields delivered to the Koren boxes are generated with a custom made digital-to-analogue converter whereas the Shakti signal was generated by a commercial sound card within a Pentium-level computer.

Statistical analyses. The basic design was a four-way analysis of variance with a single between-subject level (treatments) and three within-subject levels that included lobe, hemisphere, and session. For clarity and because of the limits of the computer software, the four-way analyses of variance were applied to each of the six increments of frequency: delta, theta, low alpha, high alpha, beta, and gamma, separately. *Post-hoc* tests were combinations of paired *t*-tests and Tukey's ($p < .05$) where appropriate.

All analysis involved SPSS software on a VAX 4000 computer. Because effect size or omega-squared estimate values, defined as the amount of variance explained, are more important for the potential clinical relevance than the level of statistical significance (once criterion has been achieved), the results of the analyses were extracted as omega-squared estimates. Statistical significance was set at $p < .05$ for all main effects and interactions.

RESULTS

The degrees of freedom and the partial omega-square estimates for each of the levels of the analyses for each of the six frequency increments are shown in Table 1. The single statistically significant interaction with treatment occurred for the relative change in power within the 10.5 Hz to 13 Hz alpha band. This effect was evident for each subject within the treatment.

TABLE 1. Partial omega-squared estimates (amount of variance explained) for the various components of the analyses for relative changes in power within six ranges of electroencephalographic activity for subjects exposed to sham fields, a burst-firing pattern through the temporal lobes or the Shakti treatment

Source	*df*	*Delta*	*Theta*	*Lo Alpha*	*Hi Alpha*	*Beta*	*Gamma*
Treatment (T)	2,9	08	03	06	10	10	12
Lobe (L)	3,27	06	02	04	06	01	14
G × L	6,27	09	19	13	06	08	07
Hemisphere (H)	1,9	51**	32	35*	49*	46*	04
G × H	2,9	28	43	26	14	30	26
Session (S)	2,18	02	09	23	19	10	08
G × S	4,18	09	06	20	27	06	13
L × H	3,27	30*	29*	46**	56**	42**	07
G × L × H	6,27	08	21	28	20	27	17
L × S	6,54	24*	18	09	12	14	18
G × L × S	12,54	06	15	16	20	13	14
H × S	2,8	03	06	13	07	09	11
G × H × S	4,18	14	12	23	26	14	26
L × H × S	6,54	11	06	22*	19	15	07
G × L × H × S	12,54	22	14	24	32*	15	12

*$p < .05$; **$p < .01$.

As shown in Figure 1, subjects exposed to Shakti for three sessions displayed a relative decrease in power within the 10.5 Hz to 13 Hz band one week after the first session (just before the second treatment). One week after the second session (just before the third treatment) the values were near baseline whereas one week after the third session with Shakti there was an increase in power within this band.

Post hoc t-tests indicated that the primary source of the statistically significant interaction was due to the absence of this change over the three weeks over the right occipital region for those who received the Shakti treatment compared to the other seven regions of the brain within the treatment and the similarity of power ratios for both the left and right occipital region for subjects exposed to the sham field or to the burst-firing fields from the Koren boxes. *Post hoc* analysis of the significant changes *within* the group that received Shakti indicated that the most statistically significant increases in relative power within the 10.5 Hz to 13 Hz range between the first and third treatments was over the left frontal, left parietal, and the right temporal lobes.

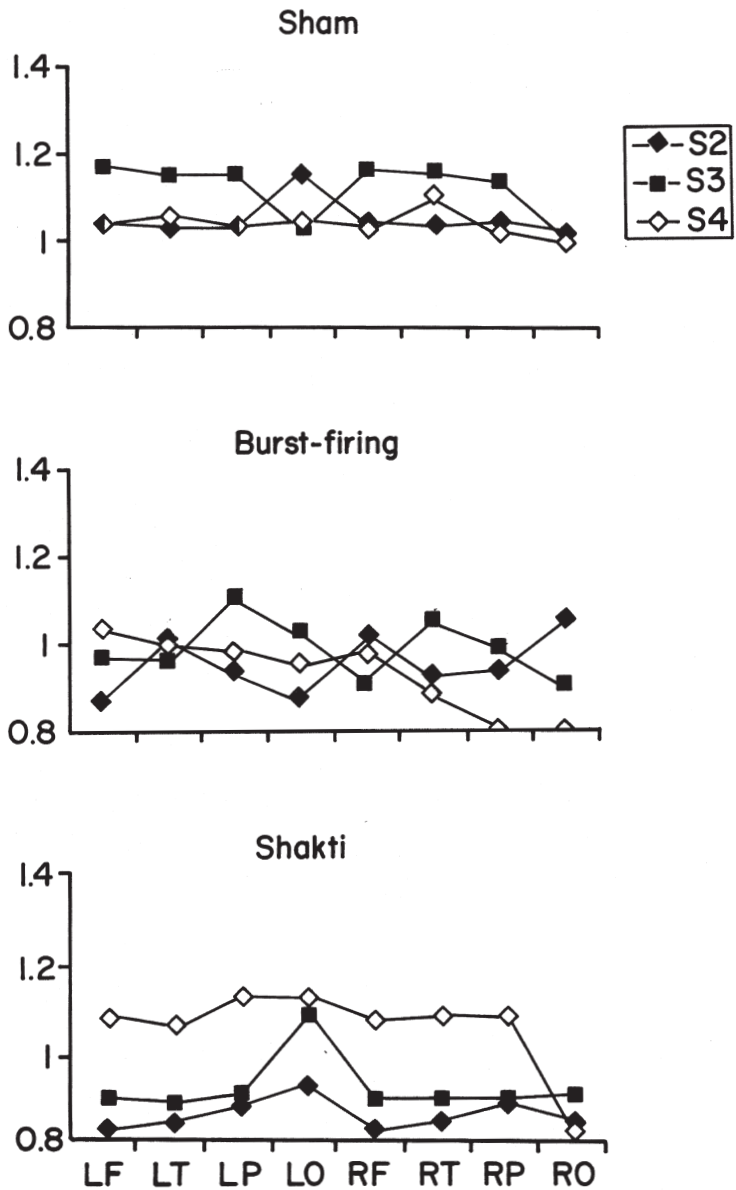

FIGURE 1. Relative ratios of power over the left and right prefrontal, temporal, parietal, and occipital regions within the 10.5 Hz to 13 Hz band one week after 30 min exposures to either sham fields, burst-firing bitemporal stimulation, or Shakti, for each of three weeks.

DISCUSSION

The purpose of this study was to discern if quantitative changes in the relative power within traditional bands of electroencephalographic activity would occur with repeated exposures to one of two different methods of neuromagnetic stimulation relative to sham conditions. The authors had decided to measure the electroencephalographic activity *before* each weekly treatment in order to detect any potential residual or cumulative effects from the previous treatment. Baker-Price and Persinger (1996) had found that after three weekly treatments with the burst-firing pattern method of application (Koren boxes) employed in this study significant reductions in "chronic" mild to moderate depression was evident for patients who had sustained closed head injuries one to two years previously. The effect size was larger than that obtained by more intense fields from Transcranial Magnetic Stimulation.

That weak (microTesla or less) complex magnetic fields can produce acute effects within electroencephalographic signatures has been reported. Persinger et al. (2000) demonstrated that a frequency-modulated pattern known to facilitate electrical seizures in rats with histories of limbic epilepsy induced both an apparitional experience and paroxysmal electroencephalographic activity over the temporal lobes of a person who had experienced an apparitional episode several years before the experiment. Persinger et al. (1997) found that electroencephalographic signatures consistent with entrainment occurred in normal individuals but only after several different configurations of complex patterns had been successively presented during a short period.

Even weaker fields have been shown to affect electroencephalographic activity. Subrahmanyam et al., 1985) reported qualitatively obvious changes that appeared to be sensitive to geomagnetic orientation in subjects when wave forms simulating continuous geomagnetic pulsations with intensities within the nanoTesla range were applied. Extracranial application of picoTesla magnetic fields with a more statistical range of frequencies (2 Hz to 7 hz) and applied from a complex matrix of coils has improved symptoms in patients with a variety of syndromes including multiple sclerosis and complex partial epilepsy (Sandyk, 1992; Anninos et al., 1991).

In the present study there were no statistically significant differences in the ratios of power within the six different traditional bands of electroencephalographic frequency for the subjects exposed to the sham field or to the burst-firing magnetic field applied through the four sets of solenoids employed by Baker-Price and Persinger (1996). We had selected the procedure of comparing the power from each of the prefrontal, temporal, parietal, and occipital regions for both hemispheres from each session to the baseline values in order to minimize the effects of individual differences and to enhance any subtle effects.

There are several reasons the burst-firing fields may not have produced a significant change in power within the wide bands of electroencephalographic activity monitored over sessions. First, the volunteers were not depressed and had not sustained any recent brain traumas. It is possible that, like aspirin that reduces body temperature in hyperthermic but not euthermic individuals, these fields do not produce long-term changes in the relative power of the brain activity of normal individuals.

Second, the frequency band employed may have not optimally discriminated the effects of these fields. In a more recent study with another set of patients, Baker-Price and Persinger (2003) found that after 5 weekly treatments there was a significant increase in the spectral power within the 13 Hz to 15 Hz range in patients who had received the burst-firing field over the temporal lobes (the same procedure as the present study) but not over the left prefrontal region. These researchers had manually counted the proportions of alpha rhythms within the record.

The subjects exposed to the Shakti treatment showed a systematic decrease in the overall relative power compared to baseline within the 10.5 Hz to 13 Hz range after one treatment, followed by a return to baseline after 2 treatments, and then a relative increase in compared to baseline after 3 treatments. Although the effect was subtle, it was within the range that might be associated with conspicuous subjective experiences. According to the creator of Shakti, Todd Murphy (personal communications, 1999 through 2003), many subjects who have utilized Shakti report an enhanced but transient visual vigilance during successive treatments that is attributed to the subsequent encouragement of spiritual and private development.

Whether or not these subjective experiences are the cognitive correlates of the relative changes in electroencephalographic power within this range must still be evaluated. In another study (Tsang & Persinger, 2003) volunteers that were exposed to the Shakti treatment for five successive days did not show any significant changes in psychometric measurements of mood compared to a sham-field group. There were also no significant differences between the groups, when each person was compared to his or her daily baseline measurements before each daily treatment began, for heart rate, skin conductance (galvanic skin response), or peripheral (plethysmographic) blood flow.

Perhaps the most unusual component of the electroencephalographic profile following the three weekly treatments of Shakti was the absence of change in activity relative to baseline only over the *right* occipital lobe. That the effect was not artifact from the equipment, measurement, or software was suggested by the absence of this effect from the other two groups. The absence of the relative increase in power over the right hemisphere over sessions might be expected to be associated with an increase in some other band whose effect was not sufficient to be revealed as statistically significant because of our sample size.

Three general conclusions can be derived from this study. First, the more spatial and temporally complex configuration of weak magnetic fields from the Shakti device produced the most significant relative change in electroencephalographic power over the weekly trials. Second, the effects of a single session were relatively permanent because the quantitative electroencephalographic measurements were completed *before* each weekly session. Third, neither the reports of the subjects nor the electroencephalographic measurements suggested any negative consequences of the exposures.

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